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Sexual orientation and neurocognitive ability: A meta-analysis in men and women

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Abstract

The cross-sex-shift hypothesis predicts that homosexual men and women will be similar in certain neurobehavioral traits to their opposite-sex counterparts. Accordingly, it predicts that homosexual men should perform in the direction of heterosexual women, and homosexual women in the direction of heterosexual men, on neurocognitive tests that show normative sex differences. We conducted a meta-analysis on the relationship between sexual orientation and cognitive performance, and tested the effects of potential moderating variables separately by sex. A total of 106 samples and 254,231 participants were included. The meta-analysis revealed that homosexual men performed like heterosexual women in both male-favouring (e.g., spatial cognition) and female-favouring (e.g., verbal fluency) cognitive tests, while homosexual women performed like heterosexual men only in male-favouring tests. The magnitude of the sexual orientation difference varied across cognitive domains (larger for spatial abilities). It was also larger in studies comparing exclusive heterosexuals with exclusive homosexuals compared to studies comparing exclusive heterosexuals with non-exclusive homosexuals for both sexes. The results may narrow down potential sites for sexual orientation-related neural differences.

Keywords: sexual orientation; cognition; meta-analysis; sex differences; gender homosexuality; spatial; verbal; brain asymmetry; prenatal androgens

1. **Introduction**

Sex differences in cognitive abilities are well documented. Typically, men score higher than women, on average, on spatial tasks involving mental rotation of three-dimensional figures, spatial visualization (such as paper folding), disembedding (finding simple figures hidden in more complex forms), spatial perception (determining horizontal and vertical angles), maze navigation, spatial learning and navigation (including tests of way-finding in real-world settings as well as on computerized tests such as the Morris Water Maze), and targeting and intercepting objects. Women score higher than men, on average, on tests of phonetic and semantic fluency, verbal memory, object location memory, visual memory, facial emotion recognition, and some tests of social cognition (e.g., Coluccia and Louse, 2004; Hyde, 1981; Kimura, 1999; Voyer et al., 1995). The origins of these sex differences are disputed by scholars from across the biological sciences (including neuroscience), behavioural and social sciences (e.g., Fine, 2010; McCarthy and Konkle, 2005). However, there are likely multifactorial causes involved, such as differences in cerebral lateralization, psychosocial factors (e.g., gender socialization), and the influence of prenatal and circulating levels of sex hormones (Collaer and Hines, 1995).

Growing research shows that sexual orientation is also related to cognitive performance; most notably on tests that show normative sex differences. For example, studies of basic visuospatial abilities, spatial memory, and verbal fluency show that homosexual individuals appear shifted in the direction of the other sex (or "cross-sex shifted"). However, this pattern is task-specific and studies yield inconsistent results. Homosexual men have lower scores compared to heterosexual men on mental rotations and judgement of line orientation (and not significantly different from heterosexual women) in some studies (Collaer et al., 2007; McCormick and Witelson, 1991; Neave et al., 1999; Rahman and Wilson, 2003; Sanders and Ross-Field, 1986; Sanders and Wright, 1997; Wegesin, 1998). But one study found no differences in mental rotation and spatial perception between heterosexual and homosexual men after controlling for general intelligence (Gladue and Bailey, 1995). Studies also show that homosexual men have lower performance compared to heterosexual men in spatial navigation (e.g., Morris Water Maze tests) but better object location memory (and are no different to the performance of heterosexual women; Canovas and Cimadevilla, 2011; Hassan and Rahman, 2007; Rahman and Koerting, 2008; Rahman et al., 2003). The magnitude of this difference appears smaller for spatial navigation than for object location memory. In the verbal domain, the picture is complex with homosexual men scoring higher than both heterosexual men and women in some domains (e.g., phonetic fluency) but performing better than heterosexual men (and no differently to heterosexual women) in others (e.g., semantic fluency; Rahman et al., 2003). Yet other studies do not find sexual orientation differences in verbal ability (Gladue et al., 1990).

The cognitive performance of homosexual women is generally female-typical, except in verbal fluency and possibly targeted throwing (Hall and Kimura, 1995; Rahman et al., 2003). However, one study reported that homosexual women were lower scoring than heterosexual women on a test of spatial perception (Gladue et al., 1990). Homosexual women are under-studied compared to homosexual men in this area. Sexual orientation differences in domains related to social cognition, such as facial emotion recognition, are also poorly studied or show no group differences (Rahman et al., 2004a) or cross-sex shifts in cognitive components whose meaning is not entirely clear (e.g., homosexual men and heterosexual women appear left-lateralized when inspecting female faces on a Chimeric Faces Test; Rahman and Yusuf, 2015).

Several theoretical and methodological moderator variables may partially account for the above inconsistencies. These include cognitive domain. The more robust sexual orientation differences appear on spatial tasks compared to verbal or other non-spatial tests. Age maybe an important factor because of known age-related cognitive decline and the fact that homosexual participants are often significantly older than heterosexuals in the studies, due perhaps to recruitment practices. Thus, potentially more robust sexual orientation differences may appear in studies in which homosexual participants are significantly older than heterosexual, or may be associated with age-related variance in certain cognitive outcomes (e.g., men tending to show greater age-decline in a range of cognitive functions compared to women; Maylor et al., 2007). Education level often serves as a proxy for general intelligence but is inconsistently measured across previous studies. Finally, the exclusivity of homosexuality may be important. Prior studies either use strict definitions of sexual orientation categories (comparing exclusive heterosexuals with exclusive homosexuals; e.g., Rahman et al., 2003; McCormick and Witelson, 1991), or compare exclusive heterosexuals with non-exclusive homosexual groups (including bisexuals or the broad category of "non-heterosexual" individuals; e.g., Collaer et al., 2007; van Anders and Hampson, 2005). The inclusion of bisexual individuals may potentially obfuscate the detection of sexual orientation cognitive differences at the ends of the sexual orientation spectrum, or their inclusion may reveal that the broader category of "non-heterosexual" show a mix of male-typical and female-typical cognitive profiles.

Thus far, the balance of evidence indicates that the cognitive profiles of homosexual men are cross-sex shifted in some domains. This does not appear to be the case in homosexual women. Theoretical accounts for these differences focus on prenatal androgens acting on developing brain mechanisms underlying sexuality and associated behavioural correlates (Collaer and Hines, 1995; Ellis and Ames, 1987). Prenatal sex hormones are predicted to organise both sexual orientation and cognitive ability in sex-atypical directions among homosexual men and women. The cognitive evidence among homosexual men offers some support for this. Further support comes from girls with androgen over-exposure in-utero (due to congenital adrenal hyperplasia) who show elevated non-heterosexual attractions and male-typical spatial performance (Hines et al., 2004; Mueller et al., 2008, Puts et al., 2008). Other mechanisms may involve learning and gender-related experiences. For example, greater time spent by men on visuo-spatial activities, like videogames, compared to women may be associated with greater sex differences in certain spatial tasks, while videogame training of both sexes has been reported to reduce the sex difference in mental rotation somewhat (Barnett et al., 1997; Feng et al., 2007; Lawton and Morrin, 1999).

Cross-sex shifts in brain structure and function may underlie the behavioural differences reported above. Heterosexual men and homosexual women show a greater rightward bias in cerebral asymmetry whereas cerebral volumes of each hemisphere are more symmetrical in heterosexual women and homosexual men. A cross-sex shift was also reported in the connections from the left and right amygdalae whereby homosexual men and heterosexual women had similar connections arising from the left amygdala while homosexual women and heterosexual men had similar connections arising from the right amygdala (Savic and Lindstrom, 2008). Homosexual men (in congruence with heterosexual women) also show stronger hypothalamic activation to smelling a male-specific odorous compound compared to heterosexual men (Savic et al., 2005). Homosexual women appear shifted in the direction of heterosexual men in response to a female odor (Berglund et al., 2006).

However, other neuroanatomical findings are difficult to interpret as cross-sex shifts. One study reported a larger isthmal region of the corpus callosum in homosexual compared to heterosexual men (Witelson et al., 2008). The absence of female comparison groups means we cannot know if this difference is cross-sex shifted. Another study reported that homosexual women (like heterosexual men) had less grey matter in the perirhinal cortex while heterosexual and homosexual men did not differ (Ponseti et al., 2007). This brain region is involved in spatial memory but given homosexual and heterosexual women do not differ in this ability, the significance of the finding is not clear. Homosexual men and women also appear similar to their same-sex heterosexual peers in their neural processing of visual erotic stimuli (Ponseti et al., 2006, Safron et al., 2007; Safron et al., 2017)

In sum, the extant literature on sexual orientation and cognition is mixed, especially in relation to cognitive domains (spatial versus non-spatial), highlighting the need for meta-analytic studies. Moreover, the results of this meta-analysis could narrow the potential sites of structural and functional neural differences between people of different sexual orientation for investigation by future researchers. We therefore undertook a meta-analysis of all published studies that examined sexual orientation differences in cognitive abilities in order to better identify sources of variation between studies and assess the strength of the predicted cross-sex shift. This includes the effects of potential moderating variables including cognitive performance type (male-favouring or female-favouring), cognitive domain (spatial, verbal and other), age, education level, and exclusively of homosexuality.

2. Method

2.1. Selection of studies

We used two search methods to identify eligible articles that published between January 1980 and February 2017. First, we searched the electronic databases PubMed, PsychInfo, Google Scholar, and ProQuest, for articles examining the association between cognitive performance and sexual orientation, using combinations of the following terms: (*visuo-spatial*, or *mental rotation*, or *spatial perception*, or *spatial visualization*, or *spatial orientation*, or *spatial learning*, or *verbal fluency*, or *perceptual speed*, or *object location memory*, or *judgment of line angle*, or *judgment of line position*, or *water level task*, or *spatial memory*, or *facial emotion*, or *spatial navigation*, or *functional cerebral asymmetry*, or *cognitive*) and (*sexual orientation*, or *homosexual,* or *heterosexual*, or *non-heterosexual*, or *gay*, or *lesbian*, or *straight*). Second, references were obtained using the articles obtained in the first method. In addition, two relevant unpublished raw datasets provided by the last author were also included. We also emailed authors directly where statistics were not available in some published articles.

To be included in this meta-analysis, articles needed to meet the following inclusion criteria: (a) their main or secondary objective was to investigate the association between cognitive performance and sexual orientation; (b) they reported sufficient data, including the values of *F*, *t*, mean and *SD* of cognitive performance separately for homosexual men, heterosexual men, homosexual women, and heterosexual women, or other statistics, to determine the effect size; (c) they provided the sample size separately for homosexual men, heterosexual men, homosexual women, and heterosexual women; (d) the data that the articles provided were not repetitive. For articles we identified that did not contain enough information to compute effect sizes, we contacted the corresponding author for the relevant information.

Note that for some studies the sample was the same but the cognitive tests, and hypotheses regarding those tests, were different (these were Collaer et al., 2007; Maylor et al., 2007; McCormic and Witelson, 1991; McCormic and Witelson, 1994; Peters et al, 2007; Rahman and Wilson, 2003; Rahman et al., 2003; Rahman et al., 2003; Rahman et al., 2004a; Rahman et al., 2004b). Analyses computing the average effect size across studies using the same sample increased the pooled effect size in men slightly but the significance of effects remained the robust. There were almost no changes in women. Thus, these were classed as separate samples for the purposes of our analyses, which focused on cognitive performance type and moderators (e.g., cognitive domain).

2.2. Coding of moderating variables

(a) Sex (men or women); (b) age (coded as the mean ages of homosexual men, heterosexual men, homosexual women, and heterosexual women); (c) education level (coded as the mean years of education homosexual men, heterosexual men, homosexual women, and heterosexual women had received); (d) exclusivity of homosexuality (coded as "exclusive" when studies compared exclusive heterosexuals with exclusive homosexuals, or "nonexclusive" when studies compared exclusive heterosexuals with non-exclusive homosexuals); (e) cognitive performance type (coded as "male-favouring tasks" or "female-favouring tasks". Male-favouring tasks are defined as tasks in which heterosexual men outperform heterosexual women on average, including mental rotation, spatial perception, spatial visualization, spatial orientation, and spatial learning/navigation. Female-favouring tasks are defined as tasks in which heterosexual women outperform heterosexual men on average, including verbal fluency, perceptual speed, facial emotion recognition, and object location memory); and (f) cognitive domain (coded as "spatial-related", including tests such as mental rotation, spatial perception, spatial visualization, spatial orientation, object location memory, and spatial learning/navigation; "verbal-related" including verbal fluency; and "other" including perceptual speed, cerebral asymmetry tests, and facial emotion recognition).

Variables were coded by the first author and the entire data set checked for errors and discrepancies separately by the third author. Both first and third authors discussed and resolved any discrepancies. We included cognitive tests where performance was clearly measured and unambiguous (e.g., comprising accuracy scores, error scores, reactions times). In order to test the cross-sex shift hypothesis, the direction of normative sex differences (whether tests were male-favouring or female-favouring) were established from previous narrative or meta-analytic reviews. There were studies of sexual orientation and cognitive performance in which normative sex differences are ambiguous. For example, studies using the Chimeric Faces Test show that sex of participant interacts with sex of stimuli and stimuli type (e.g., emotion presented). Thus, one such study (Rahman and Yusuf, 2015) was not included in the present meta-analysis.

2.3. Meta-analytic procedures

The meta-analysis was performed using the Comprehensive Meta-Analysis 3.0 (Borenstein et al., 2014). First, we used the Cohen's d as a measure of effect size. Second, we used box plots to identify the outliers. These were confirmed with funnel plots to check they were true outliers and not related to imprecision. Third, we computed the combined effect sizes using the random effects model, and tested the heterogeneity of the studies by means of the I^2 statistics. Analyses were performed both including and excluding outlying ds. Fourth, in order to explore whether any heterogeneity could be explained by methodological variations between studies, we conducted moderator analyses by means of computing the Q statistics across subgroups using the random effects model. Fifth, we performed sensitivity analyses to identify potential publication bias.

The studies included in the current meta-analysis provided diverse effect size indicators. For studies providing values of Mann-Whitney U test, we used the formulas proposed by Siegel and Castellan (1988) to transform U to Z first. Then, we used the formula by Fritz et al. (2012) to transform Z to r, and then formula proposed by Rosenthal and DiMatteo (2001) to transform r to d. For studies provided values of F or t, we used the formulas proposed by Rosenthal and DiMatteo (2001) to transform these to r, and then transform r to d. When studies used two or more different measures to test the same cognitive performance type, the averaged effect size was computed.

Effect sizes in the current meta-analysis were reported as ds. In order to make the effect sizes easier to interpret, the effect sizes for studies investigating male-favouring tasks among men and female-favouring tasks among women were computed as the standardised difference between the means of heterosexual and homosexual groups. The effect sizes for studies investigating female-favouring tasks among men and male-favouring tasks among women were computed as the standardised difference between the means of homosexual and heterosexual groups. Thus, a positive *d* indicates that homosexual men and women were sex-atypical.

3. Results

3.1. Characteristics of studies

According to the inclusion criteria, the final sample of the current meta-analysis comprised 32 articles. A total of 106 independent samples and 254,231 participants were included. Details about the studies included in the meta-analysis were presented in supplementary Table 1. Sixty-four samples included data about sexual orientation and cognitive performance in men, reaching an overall sample size of 133,178. Forty-two samples included said data in women, reaching an overall sample size of 121,053.

3.2. Sexual orientation difference in cognitive performance

Outliers were detected using the box plots separately by sex (men and women) and cognitive performance type (male- and female-favouring tasks). Samples investigating sexual orientation differences in male-favouring tasks among men had three outliers favouring the hypothesized difference, and the Cohen's *d*s were 3.07 (Hassan and Rahman, 2007), 2.37 (Gladue and Bailey, 1995), and 2.33 (Sanders and Ross-Field, 1986). Studies on sexual orientation differences in female-favouring tasks among men had one outlier favouring the hypothesized difference, and the Cohen's *d* was 1.49 (Rahman et al., 2005). Samples investigating sexual orientation differences in male-favouring tasks among women had two outliers against favouring the hypothesized difference, and the Cohen's *d*s were -3.47 and -0.84 (Gladue and Bailey, 1995). Studies on sexual orientation differences in female-favouring tasks among women had two outliers, and the Cohen's *d*s were 1.25 (Rahman et al., 2003) and -0.82 (Wegesin, 1998). Supplementary Table 2 presents the pooled effect size

(Cohen's *d*) including outliers separately by sex and cognitive performance type. Sensitivity analyses revealed substantive differences in terms of both the pooled effect sizes (*d*s) and heterogeneity between analyses including and excluding outliers. Compared with analyses excluding outliers, analyses including outliers increased the pooled effect sizes and heterogeneity in men, though the significance of the effects remained robust. However, analyses including outliers increased heterogeneity significantly, and changed the significance of the effects (for male-favouring tasks) in women. Thus, results presented below exclude outliers. Forest plots are presented in Supplementary Fig 1-2.

Table 1 presents the pooled effect size (Cohen's *d*) separately by sex and cognitive performance type. Among men, heterosexual men outperformed homosexual men on male-favouring tasks, Cohen's $d = 0.46$, $Z = 10.23$, $p < 0.001$, while heterosexual men performed lower than homosexual men on female-favouring tasks, Cohen's $d = 0.21$, $Z = 4.74$, $p < 0.001$.

For women, homosexual women outperformed heterosexual women on male-favouring tasks, Cohen's $d = 0.11$, $Z = 4.11$, $p < 0.001$, while there was no sexual orientation difference in female-favouring tasks, Cohen's $d = 0.02$, $Z = 0.73$, $p = 0.464$.

The heterogeneity in the male samples was very high (the value of I^2 ranging from 81.29% to 81.76%), indicating that over 81% of residual variation was attributed to statistical heterogeneity in the effect sizes between samples. Heterogeneity in the female samples was low (the value of I^2 ranging from 29.46% to 50.61%). The impact of design heterogeneity between studies on statistical heterogeneity in effect sizes was assessed by examining potential moderators of the effect size between studies.

3.3. Analysis of moderators

Table 2 presents the results of moderator analyses separately by sex. For men and women, the effect size differed somewhat according to cognitive domain, Q (2) = 5.79, p =

0.055 and Q (2) = 7.16, $p < 0.05$, respectively. This was just statistically non-significant for men but it is the pattern of effect sizes that is important. For men, the largest effect size was found in samples testing spatial-related cognitive performance, whereas the smallest was found in samples testing "other" cognitive ability. For women, the largest effect size was found in samples testing "other" cognitive ability, whereas the smallest was found in samples testing verbal-related cognitive performance. For men and women, the effect size was significantly larger in samples comparing exclusive heterosexuals with exclusive homosexuals than in samples comparing exclusive heterosexuals with non-exclusive homosexuals, Q (1) = 14.84, $p < 0.001$ and Q (1) = 4.31, $p < 0.05$, respectively.

3.4. Meta-regression of age and education

We conducted a meta-regression to examine whether age and education level differences between heterosexual and homosexual groups were associated with sexual orientation differences in cognitive in men and women. Age and education level differences were computed as the difference between the mean age or education level of heterosexual and homosexual groups. Twenty-five studies had measured the age and 18 studies had measured the education level. Table 3 presents the results separately by sex, showing no effect of age or education level differences.

3.5. Publication bias

Begg and Mazumdar's rank correlation test and Classic fail-safe N test were conducted separately by sex to determine if publication bias was present. The results of Begg and Mazumdar's rank correlation test ($p = 0.540$ and $p = 0.960$ for men and women, respectively) provided no evidence for publication bias. This was further supported by the Classic fail-safe N test, which suggested that 4,833 and 276 missing studies would be needed to reduce the pooled effect sizes below significance for men and women, respectively.

4. Discussion

This meta-analysis produced five main findings. Firstly, homosexual men were sex-atypical in both male- and female-favouring cognitive performance, while homosexual women were sex-atypical only in male-favouring cognitive performance. Secondly, the magnitude of sexual orientation difference was larger in spatial than non-spatial domains for both sexes (but largest in men). Thirdly, moderator analyses showed that the difference was larger in studies comparing exclusive heterosexuals with exclusive homosexuals compared to studies comparing exclusive heterosexuals with non-exclusive homosexual groups for both men and women. Fourthly, there was no effect of age or education level on the sexual orientation difference in either sex. Finally, there was considerable heterogeneity in the data, especially for men.

The primary finding of this study was that homosexual men showed a cross-sex shift in their cognitive performance and that this was stronger for typically male-favouring tasks (such as mental rotation; Rahman and Wilson, 2003; Rahman et al., 2003). The overall effect sizes were smaller (Cohen's d = 0.46 and 0.21 for male- and female-favouring tasks respectively) than those documented in single studies of specific cognitive functions, and the confidence intervals were somewhat narrow (ranging from 0.17 to 0.18). However, these small-to-moderate effects are consistent with the ranges reported in studies with very large samples compared to smaller studies (e.g., Peters et al., 2007 cf. Rahman and Wilson, 2003). The effect size for women was small and appeared only for male-favouring cognitive tasks (Cohen's d = .11). There were substantially fewer studies of female-favouring cognitive tasks in women. Moderator effects were generally much smaller in women than in men. Thus, some caution in interpretation is warranted but in general, the differences appear robust. There was little evidence of publication bias and classic fail-safe N indicated that 4,833 and 276 additional studies with null effects would be needed to produce statistically non-significant group differences in cognitive performance for men and women, respectively.

We found considerable heterogeneity in our samples, particularly among men. Over 81% of the residual variation in male samples was attributable to heterogeneity between samples and that some methodological differences between studies could be attributed to the heterogeneity. Moderator analyses were conducted to explore possible sources of this variation. We found no effects of age and education level differences in either sex, although the slopes for both variables showed trends in the predicted directions. Participants were generally young (ranging from 19.12 to 35.06 years old) and highly educated (ranging from 13.22 to 17.80 years education). The ranges of the age and education level were narrow (from -8.1 to 2.8, and from -3.03 to 2.52, respectively). This narrow range may explain the non-significant effects of age and education reported here.

Cognitive domain was an important factor for both sexes. For men, effect size was highest for spatial tasks, moderate for verbal tasks, and small for other tasks. For women, effect size was higher for other tasks and spatial-related tasks (the effect size difference between other and spatial-related tasks was very small, 0.01), and small for verbal-related tasks. This suggests that spatial tasks are most sensitive to sexual orientation differences, perhaps because they also tend to show the largest and most stable normative sex differences (Voyer et al., 1995). However, across both sexes, the number of samples testing verbal and other-cognitive tasks was substantially smaller, especially for women (Table 2). The “other” tasks also encompass a broad range of abilities including perceptual speed (e.g., digit-symbol subtests), mathematical cognition (e.g., arithmetic and number comparisons), mechanical knowledge (Vincent Mechanical Diagrams test), face and emotion recognition (e.g., Reading the Mind in the Eyes test), and one linguistic measures of functional cerebral asymmetry (dichotic listening). These tasks show small normative sex differences and so we did not expect large sexual orientation to be found.

In both sexes, exclusivity of homosexuality mattered. Samples comparing exclusive heterosexuals and homosexuals resulted in larger effect sizes than those comparing exclusive heterosexuals with non-exclusive homosexuals. This suggests that the inclusion of a broader category of non-heterosexuals (encompassing individuals with bisexual or more sexually fluid sexual interests) may potentially obfuscate the detection of sexual orientation cognitive differences. Thus, future studies should better assess the full range of sexual orientation and apply appropriate thresholds for categorising different sexual orientation groups (Xu and Zheng, 2016). Again, the number of samples comparing exclusive heterosexuals with non-exclusive homosexuals was substantially smaller than exclusive-only comparisons (Table 2). Other unmeasured factors may be important in terms of the heterogeneity reported here. These include participant factors. Some studies oversampled from university or urban community sources (e.g., Rahman et al., 2003) while others relied on online survey participants (e.g., Peters et al., 2007). This may have produced some sampling biases, common in research with difficult-to-reach or minority populations (Kuyper et al., 2016). Homosexual men and women who are more open about their sexual orientation may be more likely to respond to study advertisements than those who are less open, or live in rural locales. However, there is no strong a-priori reason for predicting that homosexual men and women who were open about their sexuality would have different patterns of cognitive performance than those who were not.

Study quality may also be a factor. Online studies, while generally being able to better access difficult-to-reach groups and yield large samples, lack experimental control over test administration compared to laboratory studies. All studies in the current meta-analysis were cross-sectional in nature (none were longitudinal), some used factorial designs while others did not, and three studies used the BBC SexID survey resulting in a very large, cross-national sample ($N > 250{,}000$).

Overall, our findings are consistent with prior demonstrations of a cross-sex shift in the cognitive performance of homosexual men, while the association is much weaker in women and appears only on male-favouring tasks (Collaer et al., 2007; McCormick and Witelson, 1991; Neave et al., 1999; Peters et al., 2007; Rahman and Wilson, 2003; Rahman et al., 2003). The findings are also supportive of the prenatal androgen model which predicts that homosexuals of both sexes should show cross-sex shifts in their neurobehavioural profiles in line with the atypical shift in their sexual partner preference (Ellis and Ames, 1987; Rahman, 2005). However, as we did not directly test neurobiological mechanisms in this study, this requires further research. The extant neuroimaging evidence is nevertheless consistent with this central prediction (e.g., Savic and Lindstrom, 2008). Our results could narrow down potential hypothesised sites of structural and functional neural differences between people of different sexual orientations. For example, stronger differences in spatial domains could implicate parietal, occipital and hippocampal contributions to sexual orientation-related differences relative to frontal contributions (which are better tapped by verbal abilities). This does not rule out the possibility that learning and differential socialization also matter. Retrospective and prospective studies have found that homosexual men and women are more gender nonconforming in childhood and adulthood than their heterosexual counterparts (Bailey and Zucker, 1995; Lippa, 2008; Xu and Zheng, 2015). These gender nonconforming behaviours may influence time spent in sex-typical activities (e.g., male-typical activities such as playing videogames and other spatial behaviours) that later cascade into cross-sex shifted cognitive differences in adulthood. Studies that indicated that the sexual orientation-differences in some cognitive functions appeared cross-nationally may argue against a socialization explanation (e.g., Collaer et al., 2007; Peters et al., 2007). However, insofar as childhood gender nonconformity (CGN) is a cross-cultural feature of same-sex attracted individuals (Bailey et al., 2016); CGN may still influence engagement with sex-typed activities which promote the acquisition of sex-specific cognitive skills later in life. Cross-sectional studies which do test the association between recalled CGN and cognitive performance tend to find small associations or only for specific test components (e.g., Hassan and Rahman, 2007; Rahman et al., 2014). This issue requires further investigation in studies that measure gender behaviour and activity, sexual orientation, and cognitive performance prospectively. Our results are also silent on whether basic differences in processes such as attention, executive, or sensorimotor function are responsible for the sexual orientation differences in higher cognitive functions.

The current meta-analysis had several other limitations. First, the heterogeneity between studies exploring male samples included in the current meta-analysis was high. The methodological variation (e.g., cognitive domains, exclusivity of homosexuality) we suggested could only be attributed partially to the heterogeneity. Second, the ranges of the age and education level differences were narrow, which may potentially obfuscate the detection of effects of age and education. Third, we could not test the effects of additional variables contained within some of the studies (e.g., measures of handedness and gender behaviour) due to the small sample size. In addition, we were unable to test for moderation by IQ because many studies did not include standardised measures of general intelligence. However, we did control for education level differences which may serve as a proxy for IQ. We were also unable to test for moderation by handedness because most studies recruited only participants who were predominantly or exclusively right-handed. Non-significant findings may be less likely to be published thus biasing our meta-analysis. However, our fail-safe tests indicated that a very large number of null findings would be needed to substantially reduce the differences reported.

In sum, the present findings suggest that there are sexual orientation-related differences in certain cognitive functions that follow the pattern of a cross-sex shift, especially in men.

Cognitive domain and exclusivity of homosexuality appear to be significant moderators of these differences. Future work should examine whether sexual orientation-related cognitive differences are associated with structural and functional brain differences and quantify the neurodevelopment of this association over the life-course.

Conflict of interest

The authors declare there are no conflicts of interest

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Table 1
The pooled effect size (Cohen's *d*) separated by sex and cognitive performance type.

Sex	Cognitive Performance Type	*K*	Mean	Range (Min, Max)	Lower limit[a]	Upper limit[a]	I^2(%)
Men	Male-favouring	37	0.46***	(-0.37, 2.01)	0.37	0.55	81.76
	Female-favouring	23	0.21***	(-0.78, 1.24)	0.12	0.29	81.29
Women	Male-favouring	25	0.11***	(-0.47, 0.72)	0.06	0.17	29.46
	Female-favouring	13	0.02	(-0.26, 0.42)	-0.03	0.07	50.61

Note: *K* = number of samples; Mean = pooled effect size (Cohen's *d*); I^2 = between-study heterogeneity statistic; Range = the min and max of the observed effect size (Cohen's *d*).
[a] 95% confidence interval.
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Table 2
Results of moderator analyses separated by sex.

Sex	Variable	K	Mean	Lower limit[a]	Upper limit[a]	Q_b
Men	Cognitive domain					5.79[b]
	Spatial-related	42	0.44	0.35	0.53	
	Verbal-related	10	0.32	0.14	0.49	
	Other	8	0.17	-0.04	0.39	
	Exclusivity of homosexuality					
	Exclusive	57	0.43	0.35	0.50	14.84***
	Nonexclusive	3	0.07	-0.09	0.24	
Women	Cognitive domain					7.16*
	Spatial-related	28	0.09	0.05	0.13	
	Verbal-related	4	-0.02	-0.10	0.05	
	Other	6	0.10	-0.08	0.28	
	Exclusivity of homosexuality					
	Exclusive	27	0.13	0.06	0.19	4.31*
	Nonexclusive	11	0.04	-0.01	0.09	

Note: K = number of samples; Mean = pooled effect size (Cohen's d); I^2 = between-study heterogeneity statistic.
[a] 95% confidence interval.
[b] $p = 0.055$
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Table 3

Results of meta-regression analysis separated by sex.

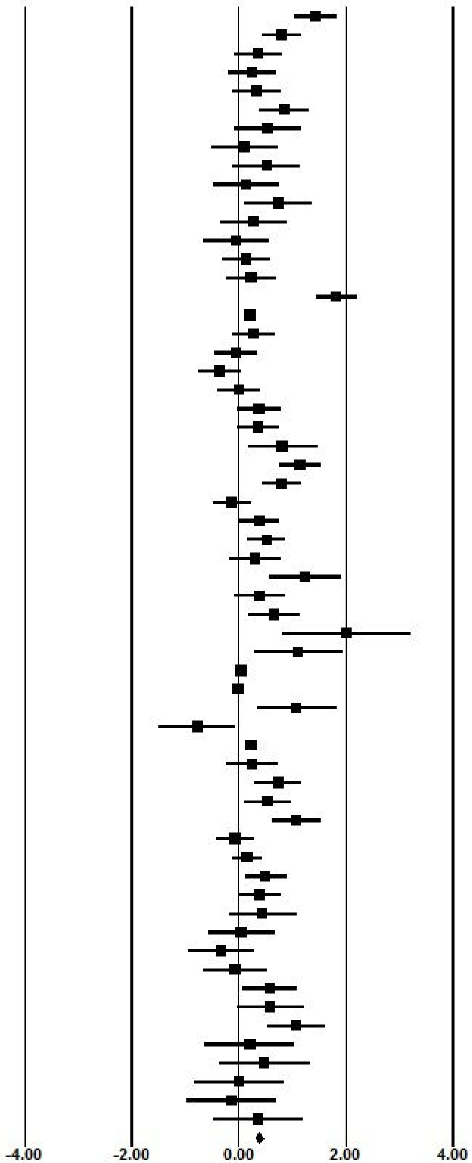
Sex	Variable	Slope	Standard error	*p*
Men	Age difference	-0.03	0.03	.323
	Education level difference	0.07	0.08	.379
Women	Age difference	-0.05	0.04	.195
	Education level difference	0.06	0.08	.459

Supplementary Table 2.
The pooled effect size (Cohen's *d*) separately by sex and cognitive performance type

Sex	Cognitive Performance Type	*K*	Mean	Range (Min, Max)	Lower limit[a]	Upper limit[a]	I^2(%)
Men	Male-favouring	40	0.57***	(-0.37, 3.07)	0.47	0.67	88.90
	Female-favouring	24	0.23***	(-0.78, 1.49)	0.15	0.32	82.91
Women	Male-favouring	27	0.01	(-3.47, 0.72)	-0.11	0.12	89.05
	Female-favouring	15	0.09	(-0.82, 1.25)	-0.00	0.17	79.88

Note: *K* = number of samples; Mean = pooled effect size (Cohen's *d*); I^2 = between-study heterogeneity statistic. Range = the min and max of the observed effect size (Cohen's *d*).
[a] 95% confidence interval.
[a] 95% confidence interval.
*p < 0.05; **p < 0.01; ***p < 0.001.

Std diff in means and 95% CI



Statistics for each study

Study name	Std diff in means	Lower limit	Upper limit	Relative weight
Rahman & Wilson (2003)sample1	1.430	1.029	1.831	1.90
Rahman & Wilson (2003)sample2	0.800	0.428	1.172	2.08
McCormic & Witelson (1991)sample1	0.360	-0.093	0.813	1.61
McCormic & Witelson (1991)sample2	0.250	-0.201	0.701	1.62
McCormic & Witelson (1991)sample3	0.330	-0.123	0.783	1.61
McCormic & Witelson (1991)sample4	0.840	0.371	1.309	1.54
Wegesin (1998) sample1	0.530	-0.101	1.161	0.98
Wegesin (1998) sample2	0.110	-0.510	0.730	1.00
Wegesin (1998) sample3	0.510	-0.120	1.140	0.98
Rahman et al.(2005) sample1	0.130	-0.490	0.750	1.00
Rahman et al.(2005) sample2	0.730	0.090	1.370	0.95
Rahman et al.(2005) sample3	0.270	-0.353	0.893	1.00
Rahman et al.(2005) sample4	-0.050	-0.670	0.570	1.01
Cohen (2002) sample1	0.130	-0.330	0.590	1.58
Cohen (2002) sample2	0.230	-0.231	0.691	1.57
Gladue & Bailey (1995) sample1	1.820	1.437	2.203	2.01
Collaer et al. (2007)sample1	0.200	0.178	0.222	5.23
Tuttle & Pillard (1991)sample1	0.270	-0.132	0.672	1.89
Tuttle & Pillard (1991)sample2	-0.060	-0.460	0.340	1.90
Tuttle & Pillard (1991)sample3	-0.370	-0.774	0.034	1.88
Tuttle & Pillard (1991)sample4	-0.010	-0.410	0.390	1.90
Tuttle & Pillard (1991)sample5	0.370	-0.034	0.774	1.88
Tuttle & Pillard (1991)sample6	0.360	-0.043	0.763	1.88
Hassan & Rahman (2007)sample2	0.810	0.165	1.455	0.94
Rahman et al. (2003) -sample1	1.140	0.754	1.526	1.99
Rahman et al. (2003) sample1	0.790	0.418	1.162	2.09
Rahman et al. (2003) sample2	-0.140	-0.498	0.218	2.18
Rahman et al. (2003) sample3	0.380	0.019	0.741	2.16
Rahman et al. (2004a) sample1	0.510	0.146	0.874	2.14
Rahman et al. (2011)	0.300	-0.171	0.771	1.53
Willmott & Brierley (1984)	1.240	0.563	1.917	0.87
Rahman & Koerting (2008) sample1	0.380	-0.093	0.853	1.52
Rahman & Koerting (2008) sample2	0.650	0.169	1.131	1.48
Sanders & Ross-Field (1986) sample1	2.010	0.808	3.212	0.31
Sanders & Ross-Field (1986) sample3	1.100	0.275	1.925	0.62
Maylor et al. (2007) sample1	0.040	0.020	0.060	5.23
Maylor et al. (2007) sample2	-0.020	-0.040	0.000	5.23
Gladue et al. (1990) sample1	1.080	0.338	1.822	0.75
Gladue et al. (1990) sample2	-0.780	-1.499	-0.061	0.79
Peters et al. (2007) sample1	0.230	0.206	0.254	5.22
McCormic & Witelson (1994) sample1	0.240	-0.252	0.732	1.44
Rahman (2017) sample1	0.730	0.285	1.175	1.65
Rahman (2017) sample2	0.530	0.091	0.969	1.69
Rahman (2017) sample3	1.060	0.600	1.520	1.58
Rahman et al. (2004b) sample1	-0.070	-0.428	0.288	2.18
Rahman et al. (2012)	0.150	-0.122	0.422	2.90
Rahman (unpublished data1) sample1	0.500	0.110	0.890	1.97
Rahman (unpublished data1) sample2	0.390	0.002	0.778	1.98
Rahman (unpublished data2)sample1	0.440	-0.187	1.067	0.99
Rahman (unpublished data2)sample2	0.040	-0.580	0.660	1.01
Halpern & Crothers (1997)	-0.330	-0.954	0.294	0.99
Shapouri et al. (2015)	-0.070	-0.684	0.544	1.02
Canovas & Cimadevilla (2011) sample1	0.570	0.054	1.086	1.34
Canovas & Cimadevilla (2011) sample2	0.580	-0.051	1.211	0.98
Hall & Kimura (1995) sample1	1.070	0.536	1.604	1.27
Witelson et al. (2008)sample1	0.200	-0.641	1.041	0.60
Witelson et al. (2008)sample2	0.470	-0.381	1.321	0.59
Witelson et al. (2008)sample3	-0.002	-0.841	0.837	0.60
Witelson et al. (2008)sample4	-0.150	-0.990	0.690	0.60
Witelson et al. (2008)sample5	0.360	-0.486	1.206	0.59
	0.373	0.304	0.442	

Study name	Std diff in means	Lower limit	Upper limit	Relative weight
Rahman & Wilson (2003)sample3	0.210	-0.149	0.569	1.47
Rahman & Wilson (2003)sample4	0.400	0.039	0.761	1.45
Wegesin (1998) sample4	0.090	-0.530	0.710	0.52
Wegesin (1998) sample5	0.190	-0.431	0.811	0.52
Rahman et al.(2005) sample10	-0.040	-0.660	0.580	0.52
Rahman et al.(2005) sample6	0.480	-0.149	1.109	0.51
Rahman et al.(2005) sample7	-0.470	-1.098	0.158	0.51
Rahman et al.(2005) sample8	-0.260	-0.882	0.362	0.52
Rahman et al.(2005) sample9	-0.250	-0.872	0.372	0.52
Collaer et al. (2007)sample2	0.060	0.040	0.080	18.05
van Anders & Hampson (2005)sample1	0.458	-0.078	0.994	0.69
van Anders & Hampson (2005)sample2	0.421	-0.115	0.956	0.69
van Anders & Hampson (2005)sample3	0.411	-0.125	0.946	0.69
Tuttle & Pillard (1991)sample10	-0.100	-0.576	0.376	0.87
Tuttle & Pillard (1991)sample11	0.050	-0.425	0.525	0.87
Tuttle & Pillard (1991)sample12	0.150	-0.326	0.626	0.86
Tuttle & Pillard (1991)sample7	-0.030	-0.505	0.445	0.87
Tuttle & Pillard (1991)sample8	-0.200	-0.677	0.277	0.86
Tuttle & Pillard (1991)sample9	0.330	-0.149	0.809	0.86
Rahman et al. (2003) sample4	0.420	0.058	0.782	1.45
Rahman et al. (2003) sample5	0.270	-0.089	0.629	1.47
Rahman et al. (2003) sample6	0.040	-0.318	0.398	1.48
Rahman et al. (2004a) sample2	0.270	-0.089	0.629	1.47
Rahman & Koerting (2008) sample3	-0.240	-0.710	0.230	0.89
Rahman & Koerting (2008) sample4	0.310	-0.161	0.781	0.88
Maylor et al. (2007) sample3	-0.030	-0.053	-0.007	17.84
Maylor et al. (2007) sample4	0.030	0.007	0.053	17.84
Gladue et al. (1990) sample3	-0.030	-0.746	0.686	0.39
Peters et al. (2007) sample2	0.110	0.076	0.144	16.93
Rahman et al. (2008)	0.410	-0.152	0.972	0.63
McCormic & Witelson (1994) sample2	0.230	-0.278	0.738	0.76
Rahman (2017) sample4	0.090	-0.360	0.540	0.96
Rahman (2017) sample5	0.120	-0.330	0.570	0.96
Rahman (2017) sample6	0.060	-0.390	0.510	0.96
Rahman et al. (2004b) sample2	0.020	-0.338	0.378	1.48
Canovas & Cimadevilla (2011) sample3	0.360	-0.150	0.870	0.76
Canovas & Cimadevilla (2011) sample4	0.480	-0.069	1.029	0.66
Hall & Kimura (1995) sample2	0.720	-0.017	1.457	0.37
	0.078	0.033	0.124	

Statistics for each study

Std diff in means and 95% CI